AXES OF SYMMETRY IN GLOBULAR CLUSTERS

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The distribution of stars in globular clusters has been extensively studied in the past, chiefly from the standpoint of the groupings and superficial arrangements of the brightest stars or on the basis of the variation of density with distance from the center.[1] The distribution with respect to direction as well as distance has been considered briefly for ten clusters by Bailey, who found a number of asymmetrical irregularities among the brighter stars.[2] But deductions relative to the basic structure of globular clusters cannot be founded safely on the most luminous objects alone, for investigations of the colors in these systems show that the brighter stars are peculiar and perhaps not at all representative of the enormous number of faint stars which constitute the greater part of the mass.

Several points wherein globular clusters resemble our galactic system of stars have been noted in recent papers, and it was suggested that planes of symmetry may characterize the distribution of stars in clusters, as does the Galaxy that of the stars in general.[3] Although the thousand brightest stars in Messier 13 gave no definite evidence of an elliptical distribution, a study with respect to direction from the center of the star-counts published for the bright southern cluster ω Centauri[4] did verify the photographic appearance of an elongated form. In this cluster 6400 stars were counted, covering a considerable interval of apparent (and absolute) magnitude, while for only two of the ten clusters discussed by Bailey did the number appreciably exceed one thousand.

The photographs of clusters with the 60-inch reflector at Mount Wilson afford material particularly suited to the study of this problem. Plates have been obtained for nearly twenty different systems, and for some clusters exposures varying in length from one minute to several hours are available. A few plates record stars fainter than the twentieth magnitude. The method and progress of the counting have previously been reported.[5] Briefly, the study of star density on each plate is based on counts made with the aid of a superposed reseau of small squares $31''.4$ on a side. The details of the observations and counts will appear eventually in the *Contributions of the Mount Wilson Solar Observatory*. The present paper indicates one of the most important results, considered somewhat in detail for the well-known Hercules

cluster, Messier 13, and more generally for the other clusters for which plates of sufficiently long exposure are available.

The data have been arranged in a system of twelve equal sectors, and these subdivided by a series of concentric circles, according to the scheme shown in figure 1. Except for the shortest exposures, the counts within a minute or two of the center are uncertain or impossible, and for the inner ring are generally ignored in the discussion. In general, results for all such crowded regions are less reliable because of possible influence of the Eberhard effect or of similar photographic phenomena. The tedious and difficult task of counting and tabulating more than 500,000 star images was performed by Miss Van Deusen

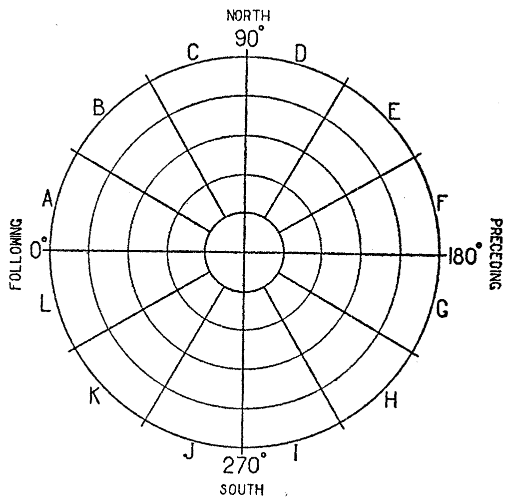

FIG. 1

of the Computing Division. Miss Richmond, also of the Computing Division, has assisted greatly in the arrangement and tabulation of the counts for the study of distribution with respect to direction from the center.

Table I and figure 2 show for Messier 13 the number of stars for successive sectors on several plates with increasing exposure time. The limits of distance from the center are 2′ and 10′, except for Plate 133, for which they are 3′ and 9′. The totals in the third column include the count or estimate of stars in the center, and also those farther from the center than the limiting distance used in the tabulation for the sectors in columns 4 to 15.

The two maxima and the two minima in each curve show immediately the presence of a well defined axis of symmetry. For plates containing only one or two thousand stars the elliptical form is little if at all

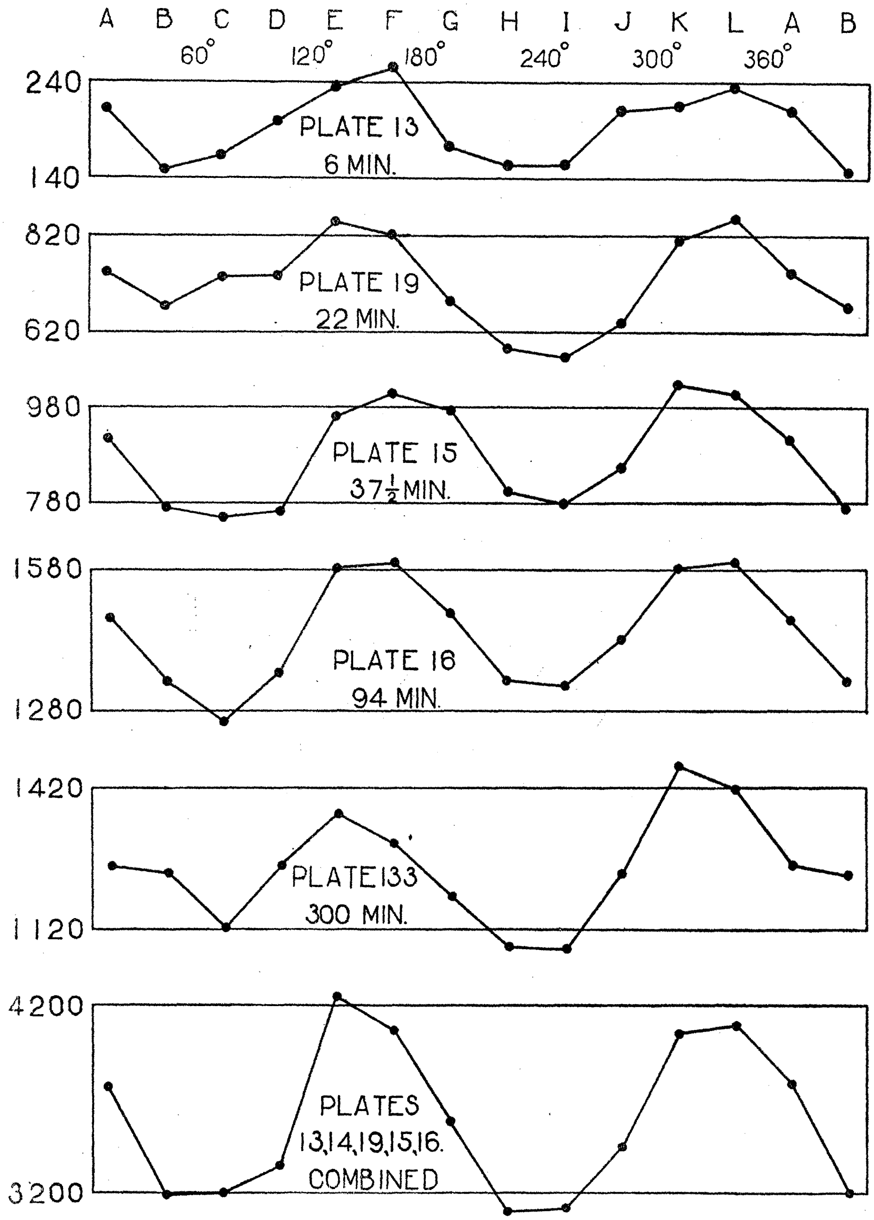

FIG. 2. AXIS OF SYMMETRY IN MESSIER 13. ORDINATES ARE NUMBERS OF STARS; ABSCISSAE ARE 30° SECTORS.

evident. To overcome the small or accidental groupings of the stars it appears necessary to have several hundred in each sector. No important systematic differences between diametrically situated sectors appear in figure 2, and, to eliminate possible errors of centering, the mean of the numbers for opposite sectors may be combined in discussing the results.

TABLE I

ELLIPTICITY FOR DIFFERENT EXPOSURES AND MAGNITUDE INTERVALS IN MESSIER 13

PLATE NO.	DURATION OF EXPOSURE	TOTAL NO. OF STARS	NUMBER OF STARS IN SECTORS											
			A	B	C	D	E	F	G	H	I	J	K	L
13	6m	5,800	211	149	163	198	235	256	174	154	154	213	214	235
14	15	7,700	433	264	296	305	309	401	259	230	284	314	420	396
19	22	14,150	744	672	734	738	852	825	684	583	569	638	814	859
15	37.5	16,600	913	770	749	763	963	1011	974	804	779	853	1026	1008
16	94	25,000	1475	1340	1261	1361	1580	1590	1486	1343	1338	1431	1580	1590
133	300	30,000	1254	1234	1126	1258	1368	1300	1187	1085	1079	1232	1463	1416
15 *minus* 13			702	621	586	565	728	755	800	650	625	640	812	773
16 *minus* 15			562	570	512	598	617	579	512	539	559	578	554	582

TABLE II

ELLIPTICITY AND DISTANCE FROM CENTER IN MESSIER 13

PLATE NO.	DISTANCE FROM CENTER	NUMBER OF STARS IN SECTORS											
		A	B	C	D	E	F	G	H	I	J	K	L
16	2′ to 4′	750	668	623	670	718	778	758	683	712	728	764	762
	4 to 6	423	361	358	394	479	438	402	352	330	386	476	464
	6 to 8	212	207	168	198	249	248	214	194	188	202	226	236
	8 to 10	90	104	112	99	134	126	112	114	108	115	114	128
133	3 to 5	624	640	560	662	712	658	629	597	586	642	788	684
	5 to 7	410	374	362	394	424	396	358	292	302	360	431	471
	7 to 9	220	220	204	202	232	246	200	196	191	230	244	261
	9 to 11	116	136	141	100	134	157	130	124	131	129	130	118

The relation of the ellipticity to brightness is also shown in Table I. Thus Plate 13 includes stars between photographic magnitudes 13 and 17.3; the next to last row of the table refers to the interval 17.3 to 19, and the last row to the interval 19 to 20. The magnitudes depend mostly on extrapolations and are subject to some uncertainty.

The plates of long exposure, Nos. 16 and 133, show a sufficient number of stars in each sector to permit a subdivision with respect to distance, the results of which are in Table II. Because of the relatively small number of stars, accidental deviations greatly mask whatever ellipticity exists in the outer ring. The counts of stars within distance 2′ on the plates of shorter exposure also show the elliptical form, and give the same general orientation.

So far as this analysis goes, therefore, the axis of symmetry in Messier 13 appears to be independent of magnitude, length of exposure, and distance from the center. It can be located visually on some of the photographs of the cluster, particularly in the burned-out central portion of the longer exposures.

TABLE III

EVIDENCE OF ELLIPTICITY IN OTHER GLOBULAR CLUSTERS

CLUSTER	PLATE NO.	DURATION OF EXPOSURE	TOTAL NO. OF STARS	NUMBER OF STARS IN SECTORS											
				A	B	C	D	E	F	G	H	I	J	K	L
M2	5	100.0m	6,500	421	404	463	508	528	521	458	416	429	458	511	464
N.G.C. 5024	102	180.0	10,100	655	686	729	730	738	699	686	692	724	679	730	656
M15	23	37.5	9,000	343	344	350	322	338	318	336	410	374	313	320	329
	24	94.0	20,500	1057	1068	1126	1070	1056	982	1103	1194	1158	1077	1044	1076
	25	312.0	26,000	1284	1357	1430	1366	1354	1316	1391	1446	1306	1322	1311	1278
M10	117	60.0	5,800	288	261	290	327	324	299	284	275	316	278	297	344
	114	180.0	12,200	810	839	801	777	818	814	798	792	836	816	830	861

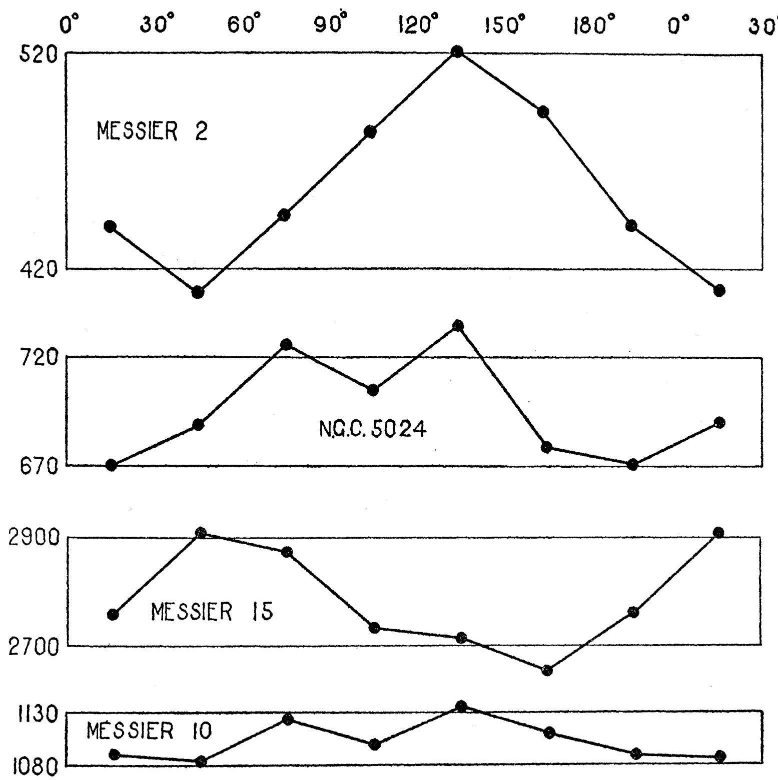

FIG. 3. AXES OF SYMMETRY IN GLOBULAR CLUSTERS. ORDINATES ARE NUMBERS OF STARS; ABSCISSAE ARE ANGLES OF DIRECTION.

An elliptical distribution of stars is not confined to the Hercules cluster. Counts for four other systems are summarized in Table III and plotted in figure 3. Three of them show unmistakable signs of elliptical form; the fourth, Messier 10, is a cluster with noticeably less condensation toward the center than usual. If the axes of symmetry in the others represent the projections of galactic-like planes, it is possible that in Messier 10 there is such a plane of symmetry inclined nearly 90° to the line of sight. The inclination to the equator of the projected major axis of Messier 13 is 152° (angle counted from *Following* through *North*). For Messier 2 and N. G. C. 5024 the inclination is 133° and 105°, respectively, while for Messier 15, which is across the Milky Way, it is 60° and is nearly parallel to the galactic plane.

[1] A bibliography of the more important of these investigations is given in *Mt. Wilson Contrib.* No. 115, (3–10), and No. 116, (4–8).

[2] Bailey, S. I., *Cambridge, Ann. Obs. Harvard Coll.*, 76, (43–82).

[3] Shapley, H., *Observatory, London*, 39, 1916, (452–456).

[4] Bailey, S. I., *Astr. and Astroph., Northfield, Minn.*, 12, 1893, (689–692).

[5] *Washington, Carnegie Inst., Year Book*, 12, 1913, (213); 13, 1914, (258).

THE SHARE OF EGG AND SPERM IN HEREDITY

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1. Assumed Equivalence of Inheritance from Both Parents.—Practically all students of heredity are agreed that there is a general equivalence of inheritance from father and mother, and O. Hertwig (1892) cites this as one of the evidences that the chromosomes only contain inheritance material, or 'Erbmasse,' since they alone come in approximately equal volumes from the two parents. Indeed phenomena of Mendelian inheritance demonstrate that, with respect to those characters which usually distinguish the two parents, there is equivalence of inheritance from each, and where offspring resemble one parent more than the other they are probably as frequently patroclinous as matroclinous. Furthermore, the distribution of chromosomes in maturation, fertilization and cleavage is exactly parallel to the distribution of Mendelian factors, which practically demonstrates that the chromosomes are the seat of these factors.

This conclusion has led many students of heredity to regard the cytoplasm of the germ cells as of no significance in heredity. Both egg and sperm contain cytoplasm which is differentiated, in the former for the